NASA Technical Memorandum 79239

UHF COPLANAR-SLOT ANTENNA FOR AIRCRAFT-TO-SATELLITE DATA COMMUNICATIONS

(NASA-TM-79239) UHF COPLANAR-SLOT ANTENNA FOR AIRCRAFT-TO-SATELLITE DATA COMMUNICATIONS (NASA) 21 p HC A02/MF A01 CSCL 17B

N79-31185

Unclas

G3/04 31987

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Prepared for the
Printed Circuit Antenna Technology Workshop
cosponsored by the New Mexico State University
Physical Science Laboratory and the Army
Research Office Physical Science Laboratory
Las Cruces, New Mexico, October 17-19, 1979

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SUMMARY

A lightweight low drag coplanar-slot antenna has been developed for use on commercial jet aircraft that will provide upper hemisphere coverage in the UHF band at receive frequencies of 468 MHz and transmit frequencies of 402 MHz. The antenna, developed under subcontract to the Government, is part of a program for the development of a system to transmit meteorological data from wide-body jet aircraft to ground users via synchronous meteorological data relay satellites. Antenna of this type are presently being flown on international commercial B747 aircraft on an experimental basis for the National Aeronautics and Space Administration (NASA)/National Oceanic and Atmospheric Administration (NOAA), Aircraft-to-Satellite Data Relay (ASDAR) International World Weather Observation Program.

The low profile antenna (23.5 cm wide by 38.1 cm long by 1.9 cm high) is a conformal antenna utilizing the coplanar-slot approach, developed under NASA subcontract by TRANSCO Products, Inc., Venice, California. The coplanar-slot approach is a recent breakthrough in conformal antennas with the advantages over the common stripline antenna of broader frequency bandwidth and improved electrical integrity over wider ranges of temperature. The antenna is circular polarized, has an on axis gain of near +2.5 dB and a HPBW greater than 90°.

1.0 INTRODUCTION

1.1 Need for Weather Data

The United States has been deeply involved in the Global Atmospheric Research Program (GARP) and has assumed responsibility for certain of the activities

which are being coordinated by the National Oceanic and Atmospheric Administration (NOAA). One of the activities is to provide an improved source of meteorological data from aircraft via satellite for long range weather forecasting [1]. The initiative for starting the Aircraft-to-Satellite Data Relay (ASDAR) Program came from a recognition that much of our world's weather originates in the data sparce area of the tropics which are primarily ocean. It was further recognized that these areas are frequently crossed by many of the modern wide-body long-range jet aircraft of the B747, DC-10, and L1011 type. These aircraft contain navigation and air data systems capable of providing the desired weather data, that is, latitude, longitude, wind speed, wind direction, altitude, and outside air temperature. The ASDAR system consists of a data acquisition and control unit to acquire, store and format this data; a clock to time the data sampling and transmission periods; and a transmitter and low-profile upper hemisphere coverage antenna to relay the formated data via satellite to the National Weather Service (NWS) ground stations as shown in figure 1.

1.2 Prototype Installation

A prototype ASDAR system for automatically transmitting this meteorological observation data from aircraft was developed by the NASA Lewis Research Center, Cleveland, Ohio, during 1975-1976. In late 1976 the NASA, on contract to Pan American World Airways (PAA) Inc., installed the ASDAR system on PAA B747 aircraft No. N657PA, with completion of flight testing, Federal Aviation Administration (FAA) approval, and Supplemental Type Certification in February 1977.

1.3 Additional Installations

In cooperation with the NOAA, ASDAR systems are installed on several B747 world-wide commercial jet aircraft and on an Air Force C141 airplane (Table 1). These systems are installed and operational on an experimental basis during the GARP time period to provide the National Weather Service (NWS) with the desired additional meteorological data. Data is being relayed from these aircraft to ground receiving weather stations around the world via the U.S. Geostationary Operational Environmental Satellites (GOES series) and the European and Japanese Weather Satellites.

TABLE 1

ASDAR INSTALLATIONS AND REPORTING TIMES

Airline	Aircraft tail number	Reporting time (min after hr)
Pan Am	PA001Z	02
KLM	KL002Z	04
SAS	SK003Z	06
Qantas	QF004Z	08
Lufthansa	LH005Z	10
Qantas	QF007Z	34
Qantas	QF008Z	36
Qantas	QF009Z	38
Qantas	QF010Z	40
USAF/MAC	US011Z	12/42
Singapore	S0013Z	16
Singapore	S0014Z	44
Singapore	S0015Z	18
British Air	BA016Z	46
British Air	BA017Z	20
South Africa Air	SA018Z	48
South Africa Air	SA019Z	22

The ASDAR data also provides the unique capability in that the transmitted latitude and longitude information automatically provides the exact location of each ASDAR equipped aircraft in real time, and provides an indication of movement of the aircraft versus flight time along the flight route via satellite to ground receiving stations.

1.4 System Performance

Performance of the systems to date has indicated excellent data coverage of aircraft flights from satellite horizon to horizon, indicating that the low-profile coplanar-slot aircraft antenna does provide acceptable hemisphere coverage at two frequencies (468 MHz RX and 402 MHz TX). A sample formatted data printout

message as received and printed by the National Environmental Satellite Service (NESS) is shown in figure 2. The data transmissions are consistently good and free of errors within the coverage area of each satellite. Figure 3 shows data from two U.S. satellites (GOES-1 at 135° W long and GOES-2 at 75° W long). This data is from six aircraft carrying ASDAR over a 1-month period. Sampling of the data occurs every 7.5 minutes (8 times per hr), with transmission of the blocks of stored data once an hour to the satellite. Figure 3 also shows the contour of constant zero degree elevation to the receive satellites as viewed from the aircraft. The data shown are from ASDAR units equipped with internal precision clocks, allowing continuous data collection and hourly transmissions to all satellites within view above the horizon. Earlier model units using the U.S. satellite time reference had somewhat limited performance near the horizon due to the time required for the ASDAR antenna/receiver to lock onto the satellite time signal, start gathering data and then transmit at the next hourly transmission period.

2.0 SYSTEM DESCRIPTION

2.1 Physical Layout

Figure 4 shows the installation of the ASDAR system in a B747 aircraft. The ASDAR power supply and electronics unit are located in the main electronic equipment area of the lower level of the aircraft. The RF coaxial cable is routed up through the main cabin area to the ceiling of the upper lounge [10.7 m (35 ft)] where it connects to the antenna at station 520. The total system weight including power supply, electronics unit, equipment rack shelves, cabling and antenna is 30.19 kg (66.56 lb).

2.2 Data Source

Data inputs to the ASDAR electronics unit are provided from the aircraft's Inertial Navigation Unit (INS) and Air Data System via the Flight Data Acquisition Unit (FDAU). The INS system provides the latitude, longitude, wind direction and wind speed as serial BCD data. The FDAU system provides altitude and outside static air temperature in the form of PCM serial data. Data is stored in the electronics unit and then transmitted to the satellite once an hour. The ASDAR transmitter ON-TIME is nominally 37 seconds during each reporting period (once per hour) during flight, except for ground testing when

the transmitter can be keyed for 2, 4, 8, and 16 transmissions per hour. The ASDAR transmitter output is 80 watts, with approximately 60 watts input at the antenna after coax losses.

2.3 System Components

The major units of the ASDAR system are shown in figure 5; the power supply, the coplanar-slot antenna and the electronics unit. The power supply and electronics unit were designed and fabricated by the Lewis Research Center and packaged in standard airline radio-rack units. The antenna was developed under contract by TRANSCO Products Inc., Venice, California, and is packaged in an aluminum casting 23.5 cm (9.25 in.) by 38.1 cm (15.0 in.) by 1.9 cm (0.72 in.) thick). The casting is contoured on the underside to fit the aircraft fuselage. The antenna, along with its 0.32 cm (0.125 in.) silicon rubber pressure-seal gasket weighs 3.12 kg (6.88 lb). Figure 6 shows the antenna mounted on the top side of the B474 "hump" at station 520. The only modifications to the aircraft fuselage for mounting the antenna is the installation of a 0.16 cm (0.063 in.) antenna doubler plate, drill one 2.7 cm (1.063 in.) hole for the RF connector feed-through, and eighteen (18) bolt holes for mounting the antenna to the aircraft.

3.0 ANTENNA

3.1 Selection of Candidate Antennas

During development of the ASDAR hardware components, a survey of available aircraft antenna types indicated that no existing antenna would meet the requirements for upper hemisphere coverage and flight qualification for use on commercial jet aircraft. Under a joint NASA/PAA effort with TRANSCO Products Inc., a low-profile, lightweight coplanar-slot antenna was developed, fabricated, and tested that would operate over both the 402 and 468 MHz frequency bands and also would meet the requirements for upper hemisphere coverage and FAA flight qualification. Environmental qualifications as required per Radio Technical Commission for Aeronautics (RTCA) Document DO-160 and Boeing Aircraft Company (BAC) Document D6-16050 were completed by TRANSCO. Flight qualification and FAA approval and certification was completed by PAA under the NASA contract. Table 2 shows the finalized specifications that were submitted for the production model antennas.

TABLE 2

ASDAR ANTENNA SPECIFICATIONS

Frequency	401.7 - 402.1 MHz TX 468.8 - 468.9 MHz RX
Impedance	50 ohm
VSWR	1.5:1 maximum
RF power	90 watts maximum for 37 seconds Maximum duty cycle 37 seconds/3.75 minutes
Axial ratio	5.5 dB maximum (at zenith)
Gain (nominal)	+1.5 dBic (at zenith)
Beamwidth (3 dB)	90°
Polarization	Right hand circular
RF connector	Type N female

3.2 Physical Characteristics

The physical characteristics of the TRANSCO antenna are summarized in table 3.

TABLE 3

TRANSCO PRODUCTS INC. ASDAR ANTENNA

Model number	213F00100-1
Type	Coplanar slot
Size	23.5 cm (9.25 in.) wide 38.1 cm (15.0 in.) long 1.83 cm (0.72 in.) thick
Weight	3.12 kg (6.88 lb) antenna 0.254 kg (0.56 lb) gasket
Gasket material	0.318 cm (0.125 in.) silicon rubber
Mounting screws	18 each type NAS514P1032-20P

The microcircuit element of the antenna is approximately 20.32 cm (8 in.) by 20.32 cm (8 in.) by 1.27 cm (0.5 in.) thick and is fitted into a milled out cavity in the larger aluminum casting (fig. 7). The casting provides the structure for mounting the antenna to the aircraft, serves as a pressure plate

around the RF connector feed-through, provides an aerodynamic fairing on the aircraft contoured surface and protects the antenna element from weather erosion.

3.3 Antenna Design Considerations

Because of the requirement for low-profile, lightweight and low-cost antennas that could be installed on commercial jet aircraft with minimum rework to the aircraft structure, the large cavity-backed antennas, cross-dipoles and dipole-over-blade antenna types were ruled out. The large protruding antennas were also ruled out since they would create a weight and drag penalty that would not be acceptable to the airlines for carriage over long periods of time. It was also requested by the airlines that a single, dual-frequency type antenna be used in order to minimize the structural rework required to the aircraft. Therefore, the simpler conformal type narrow-band microstrip radiating patch, where two separate antennas would be required, was considered as a secondary approach. Early investigations had indicated that wide band frequency operation would be difficult to achieve with the patch antenna since the input impedance varies rapidly with frequency and temperature changes [2]. Because of the extreme temperature variations due to altitude changes, frequency shift of the ASDAR signal during flight from Doppler shift, and frequency drift of the transmitter output over extended periods of time, verification of operation with the patch antenna would have required extensive development and testing efforts.

3.4 Antenna Construction

The coplanar-slot antenna selected for the ASDAR system is of a multilayer construction as shown in figure 7. The Type N RF connector is mounted on the lower side of the element cavity. The RF connector is mated to a double-stub tuned stripline feed circuit board through a four-port quadrature hybrid. The top insulator board and top ground plane for the feed circuit board also provides the structural assembly (pressure plate) for maintaining overall impedance tolerances and frequency stability. The circuit tuning stubs are pretuned both capacitively and inductively such that they reactively tune the antenna prior to final assembly, eliminating the need for further tuning after assembly and encapsulation is completed. The polycarbonate dielectric material provides the cavity loading, where the dielectric constant uniformity and fabrication

tolerance reproducibility has a significant impact on the antenna performance as to power amplification and bandwidth. The radiating patch over the dielectric cavity is fed by two orthogonally located connector posts to provide the desired circular polarized radiation pattern.

3.5 Antenna Operation

The operational description of the antenna, when considered as a transmitter, is as follows (see fig. 7) [3]: The RF energy is fed into the Type N RF connector Section C-C which transforms the feed from coax to stripline. The stripline input is fed to a 90° hybrid. The feed lines presented to the hybrid output are matched using double stub stripline techniques to a VSWR value of 2:1 or less. The feed lines are again transformed from stripline to coax at the antenna dual feed points by use of IPC connectors, shown in Section A-A. The radiating patch is fed through this arrangement at symmetrical points with a quadrature signal, thus producing circular polarization.

The presenting of a 2:1 or less VSWR at the output of the hybrid allows the isolated port to be terminated in a reactive load versus a resistive load. This method prevents excessive power being distributed in the load if the antenna resonant frequency should slightly change.

3.6 Antenna Qualifications

On completion of assembly, the antenna is encapsulated to inhibit corrosion and is then painted with an outer protective coating of white aircraft-radome ASTRACOAT material. Qualification tests were completed in conformance with airline required specifications per RTCA DO-160 and BAC D6-16050. Input impedance (VSWR) tests were measured at the center frequencies of 401.9 and 468.8 MHz for the operating frequency ranges of 401.7 to 402.9 MHz (transmit) and 468.8 to 468.9 MHz (receive). Radiation distribution plots of the upper hemisphere were made at 2° increments in azimuth and elevation at the center of the transmit and receive frequency bands. Data was taken with the test unit mounted on a large ground plane simulating the installation area on the B747 aircraft. The values were generally uniformly distributed and without deep nulls (figs. 8 and 9).

Polar plots were made at 15° increments in the vertical plane ($\phi = 0$ to 180°) for azimuths of $\theta = 0$ to 360° at the center of the transmit and receive

frequencies. Conic sections were made in planes parallel to the horizon for 0° through 90° elevation in increments of 5°. The gain of the test antenna relative to a $\lambda/4$ stub antenna was +2.5 dBci (401.9 MHz TX) and 1.0 dBci (468.8 MHz RX) at the peak of the elevation beam. A lower gain at the receive frequency was accepted in order to achieve (favor) a higher gain in the transmit mode. The gain at ±45° was near 0 dB at each of the two frequencies. The axial ratio was within the 5.5 dB specification at zenith for both frequencies. The temperature and altitude test consisted of a low temperature test at -55° C, a high temperature test at +85° C and an altitude test at the equivalent of 50 000 feet. The power handling capability of the test antenna was measured prior to and during each test by applying 90 watts CW at 401.9 MHz. VSWR measurements were made at each condition, with test results indicating normal operation. Humidity and sinusoidal vibration tests were conducted in accordance with the specified RTCA test requirements. The only exception was minor paint blistering that occurred at high temperature, which was not considered critical.

4.0 CONCLUSIONS

The coplanar-slot antenna developed by TRANSCO Products, Inc. for use on commercial aircraft has operationally demonstrated that a lightweight low-profile conformal antenna can provide consistent and reliable upper hemisphere coverage for data communications between aircraft and satellites. These prototype antenna (and ASDAR systems) have now been operational on B747 international aircraft for over 2 years with a minimum of failures. A few early antennas had experienced increasing VSWR's with time, due to moisture seepage into the cavity area around the antenna mounting screws. This condition was corrected by an improved method of sealing the cavity by TRANSCO, and by sealing around the antenna and its mounting screws during installation on the aircraft. One other antenna had been replaced as a precautionary measure during aircraft overhaul because of hairline surface cracks and leading edge erosion in the protective paint. These problem areas were corrected, and operation to date indicates highly satisfactory performance from these antenna systems.

Because of the successful performance of these prototype systems, the NOAA is now reviewing the desirability and feasibility of making ASDAR a worldwide operational system. To accomplish this effort, the electronics units would be

repackaged for improved reliability and ease of maintenance, and the antenna design would be reviewed for improved performance and lighter packaging to be more compatible for installation on other types of aircraft.

5.0 REFERENCES

1. Bagwell, J. W., and Lindow, B. G., An Airborne Meteorological Data Collection System Using Satellite Relay (ASDAR), NASA Lewis Research Center Technical Memorandum 78992, November 1978.

2. Derneryd, Anders G., Microstrip Disc Antenna Covers Multiple Frequencies, Microwave Journal, Vol. 21, May 1978, pp. 77-79.

3. Greiser, John W., Coplanar Stripline Antenna, Microwave Journal, Vol. 19, October 1976, pp. 47-49.

4. Myhre, R. W., Microstrip Antenna for Aircraft Applications, Interservice Antenna Group Workshop, Point Mugu, California, February 1979.

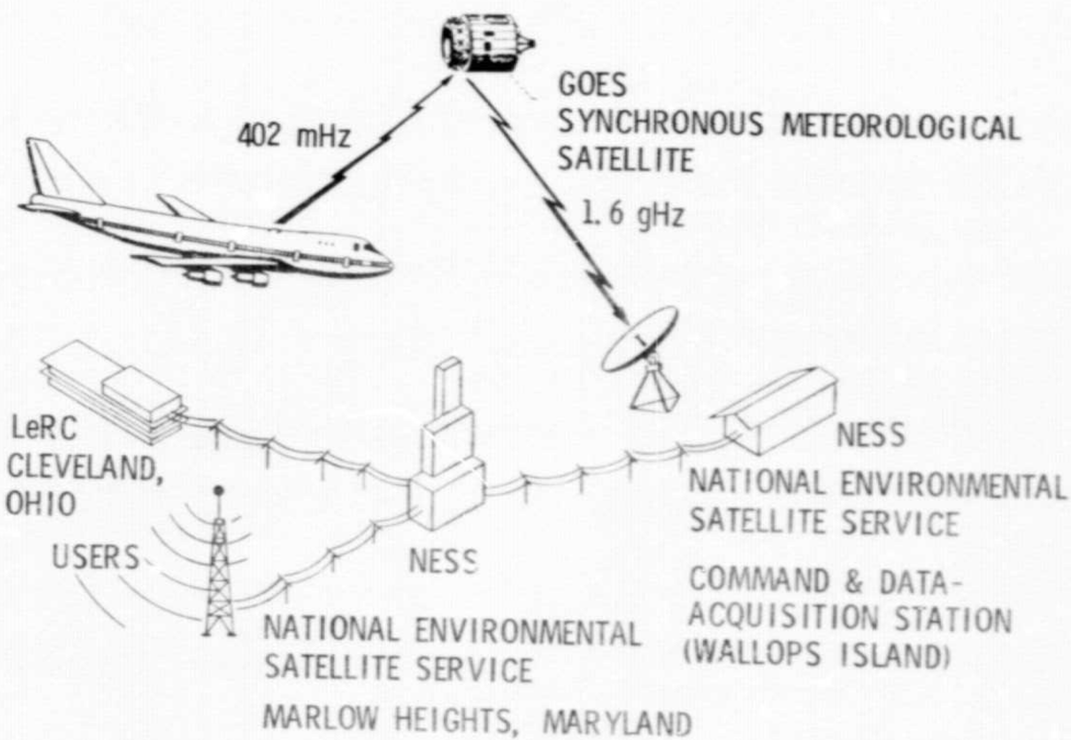

Figure 1. - ASDAR - global weather data gathering system

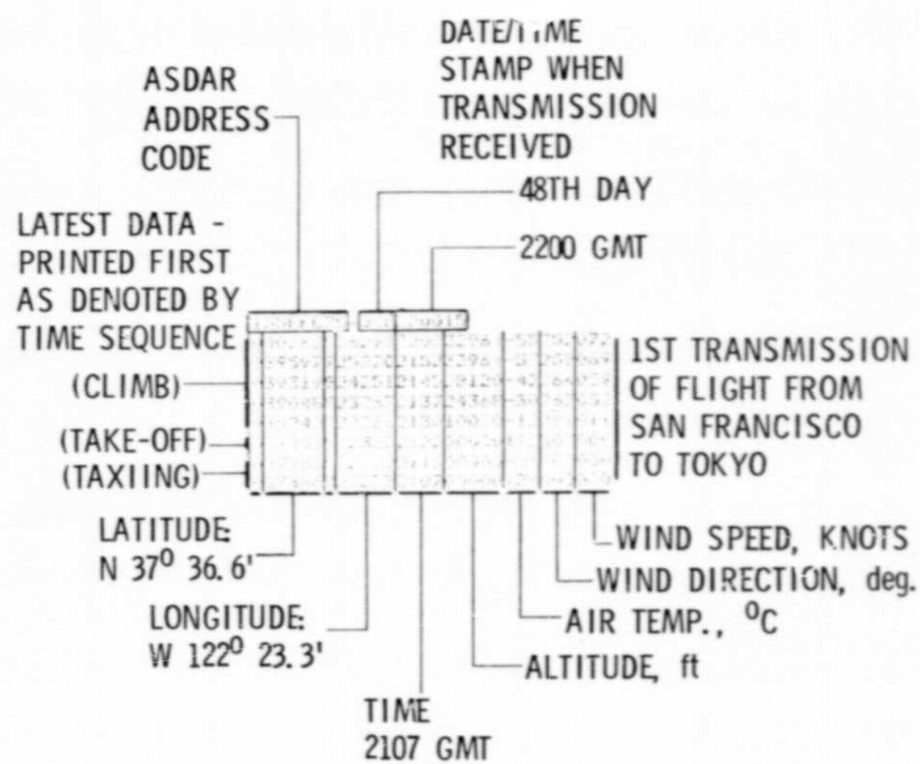

Figure 2. - ASDAR printout obtained, via satellite relay, from National Satellite Service

ASDAR DATA FROM 01/19/79 TO 02/28/79
ASDAR PLATFORM ID=A0007022

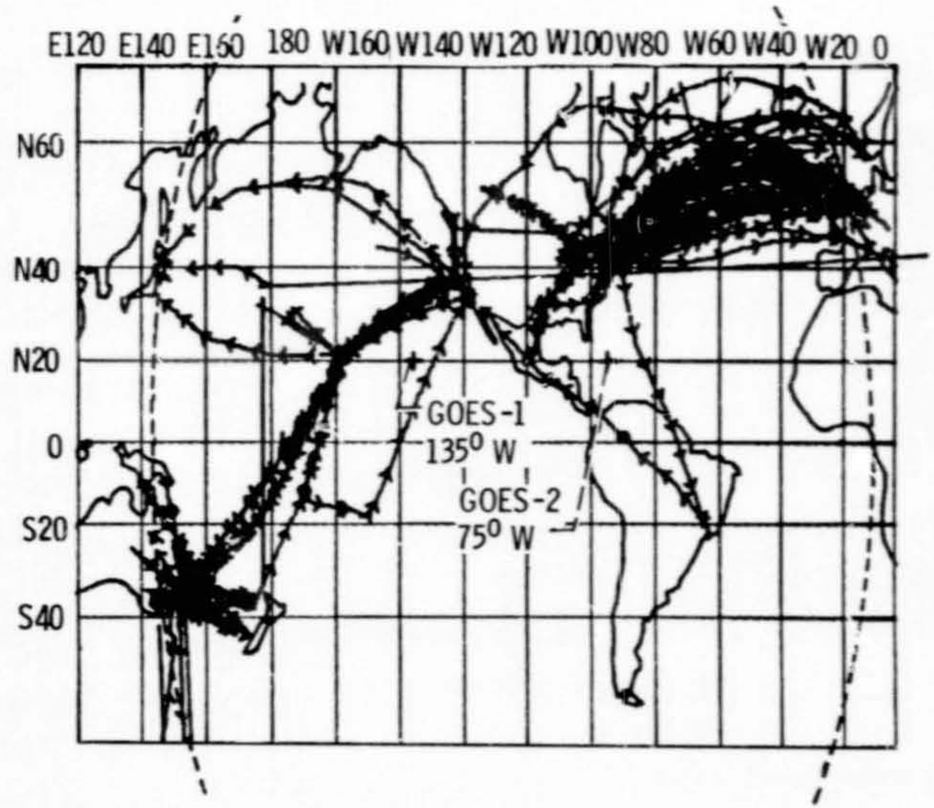

Figure 3. - Aircraft ASDAR flight data record with contour of zero degree elevation to U. S. satellites.

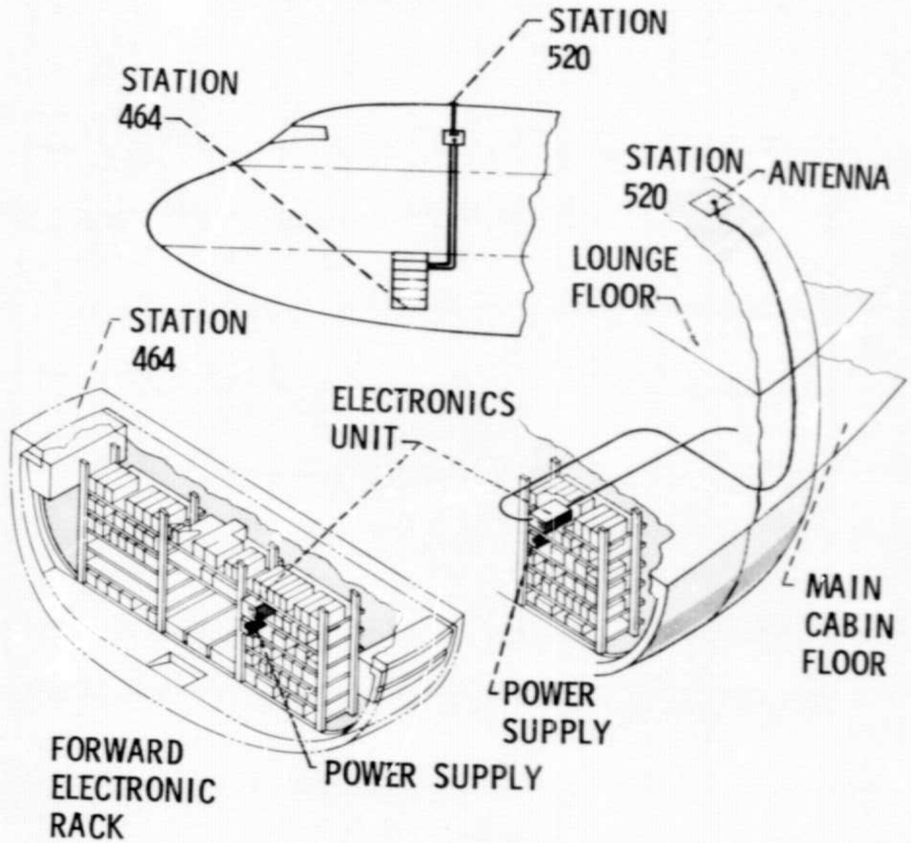

Figure 4. - B747 ASDAR system installation.

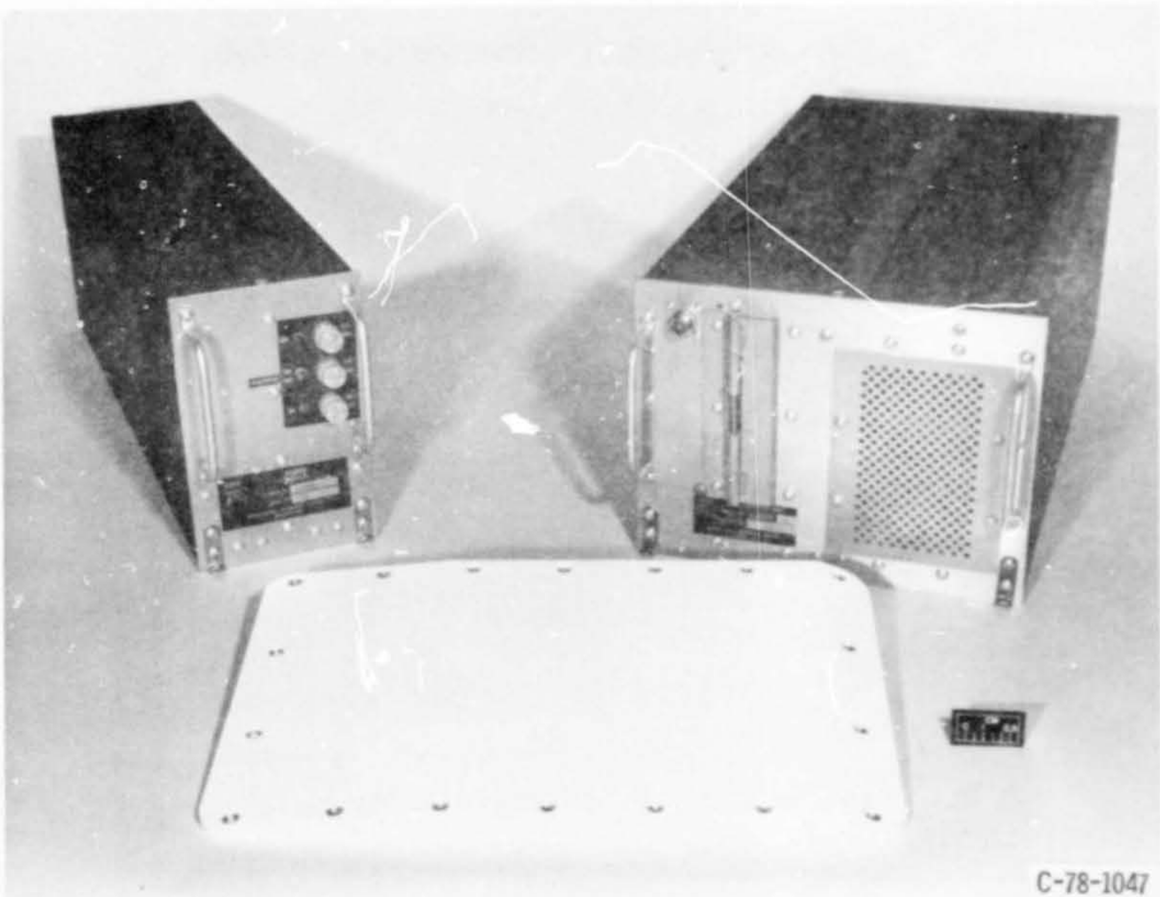

Figure 5. - ASDAR power supply antenna, and electronics unit.

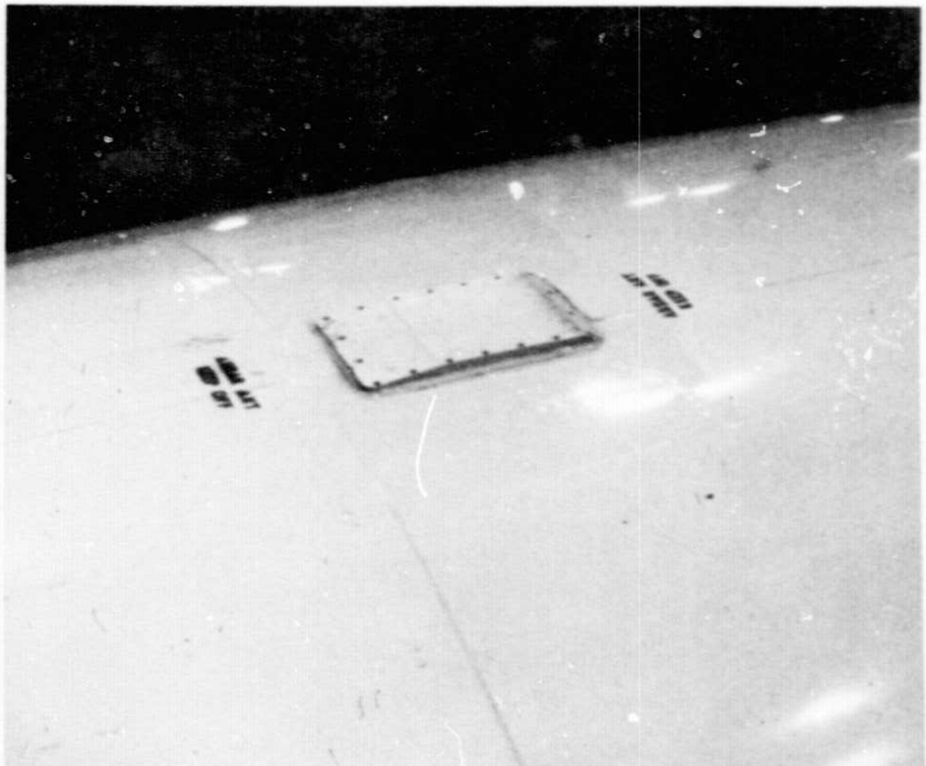

Figure 6. - ASDAR antenna installed on B747 aircraft.

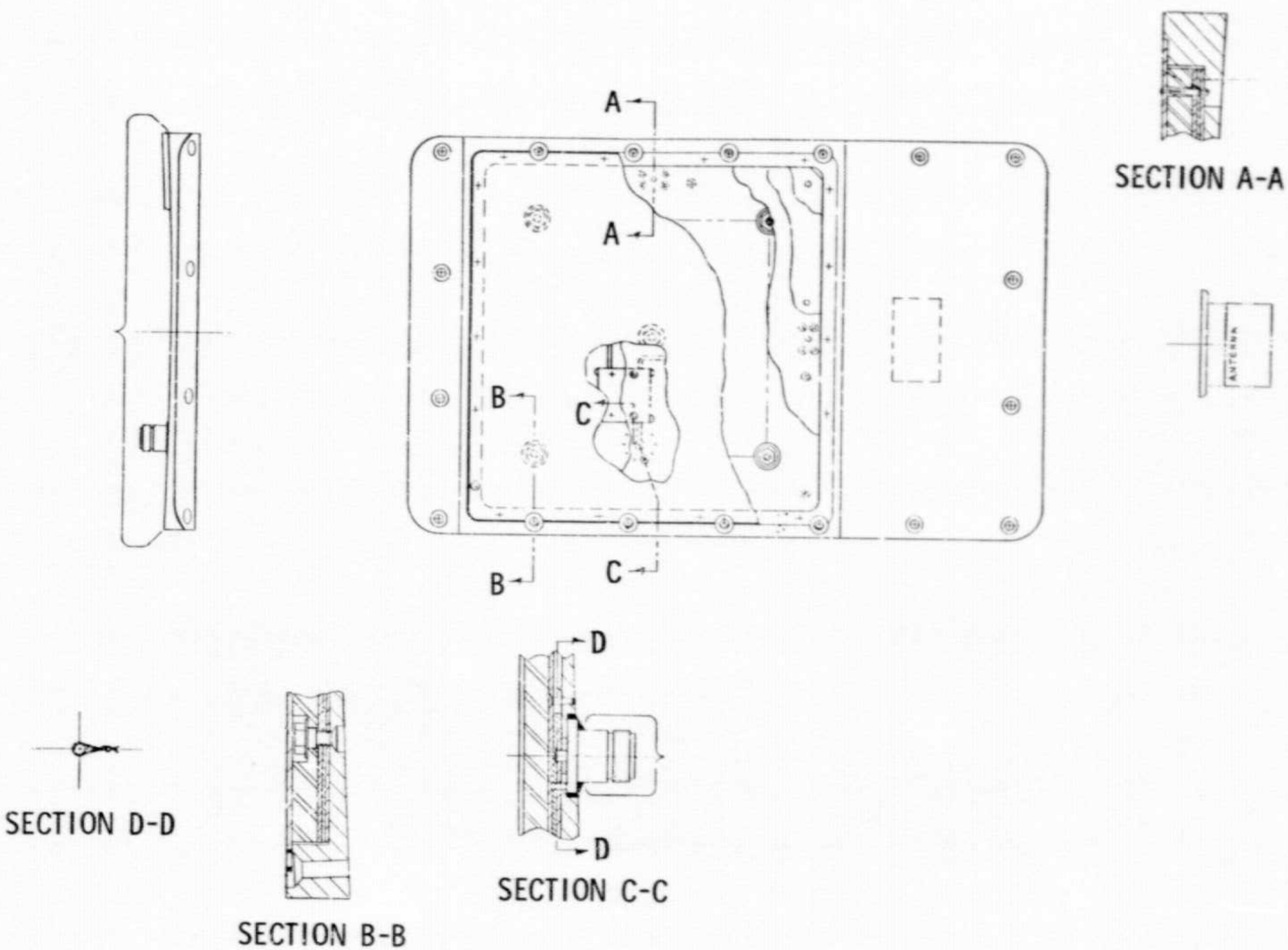

Figure 7. - Transco Products Inc. ASDAR antenna model 213F00100.

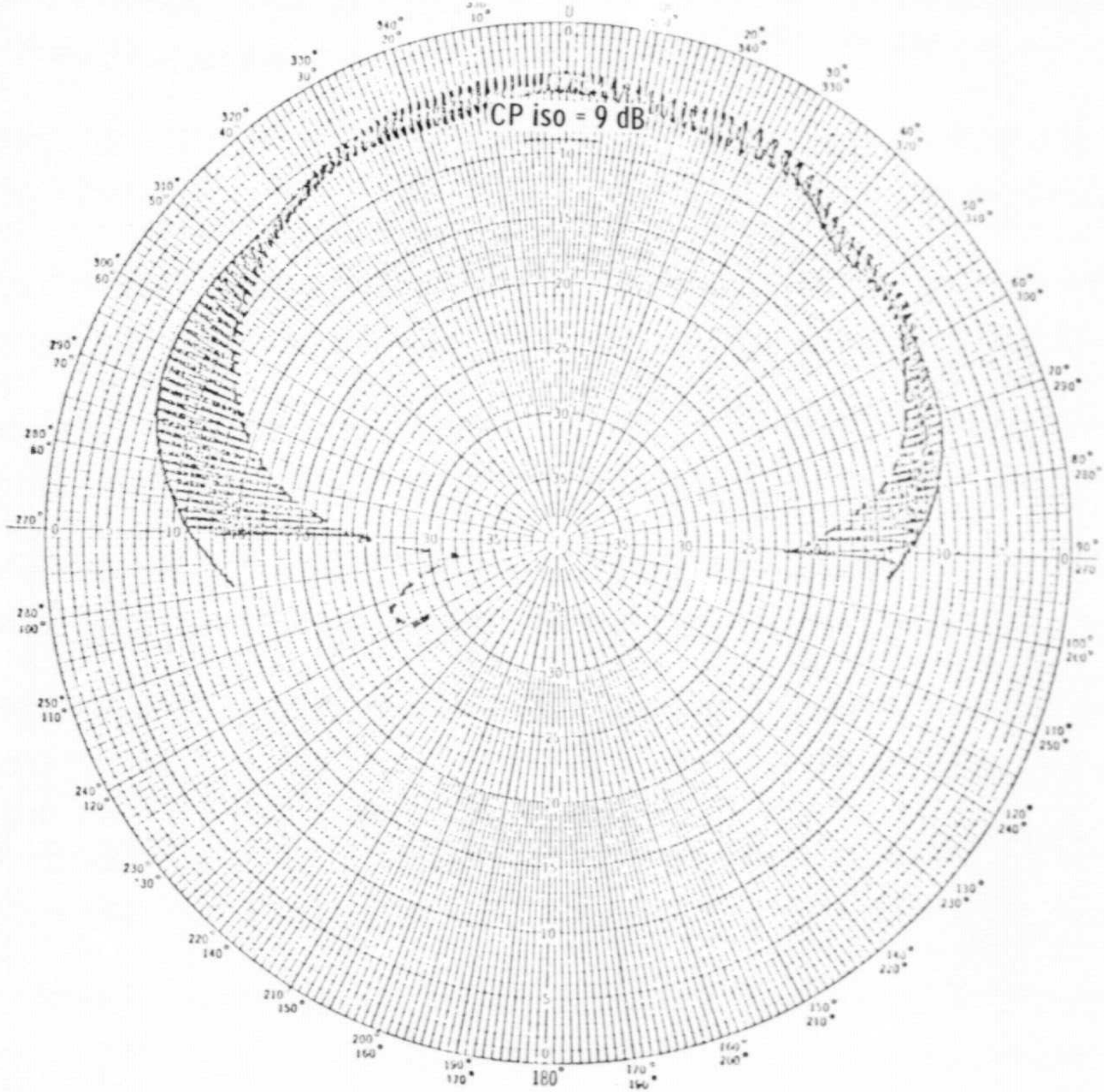

Figure 8. - ASDAR atenna radiation pattern Transco Products model 213F00100; S/N 11; ground plane mockup; freq. 401.9 MHz; aircraft pattern; roll plane.

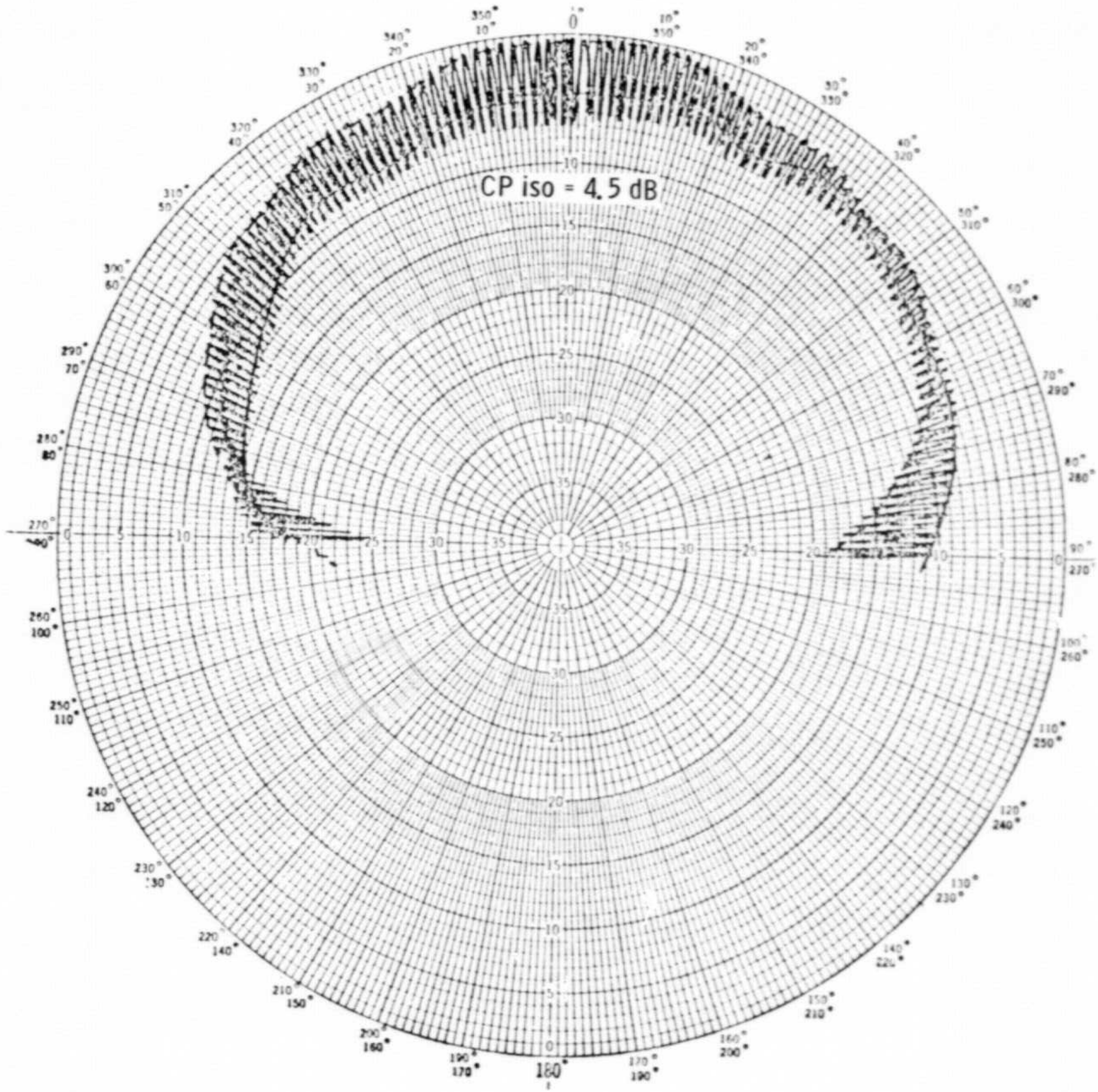

Figure 9. - ASDAR antenna radiation pattern Transco Products model 213F00100; S/N 11; ground plane mockup; freq. 468.85 MHz; aircraft pattern; roll plane.